Dimensional stability validation and sensor calibration with sub-nanometer accuracy

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High-end instrumentation such as optical systems for space science applications deal with challenging requirements on the dimensional stability not only for the employed materials but also for assembled structures. Advanced materials and connection techniques demand investigation of yet unknown properties and validation of medium to long-term if not-life time stability to the picometer level. Examples are C/SiC and CFRP materials and diffusion bonded junctions [1,2]. Furthermore, highest level position sensing and control may be in need of displacement sensors that not only do provide picometer-level sensitivity (resolution) and precision (stability) but also accuracy. This accuracy demands for calibration methodologies with appropriate statistical and systematic measurement uncertainty budget and with traceability to international standards. Examples are capacitive displacement sensors, available with very high sensitivity and excellent linearity.

Optical displacement interferometry is a promising approach to meet these validation and calibration needs. Non-contact optical interfacing in heterodyne and homodyne interferometry minimizes the perturbation on the sample under test while providing high sensitivity in phase measurement as it scales with the optical wavelength. Also many possible configurations and large displacement range are supported. Even higher sensitivity and precision for displacement measurement is available by means of Fabry-Pérot interferometry (FPI), facilitated by the high frequency selectivity of the optical cavity resonance. Given the versatility in choice of the translation-actuated measurement interface, e.g. an electrically conductive one for capacitive sensors, FPI is particularly useful for the calibration of ultra-precision displacement sensors.

We report on progress in our research on (i) displacement interferometry for dimensional stability measurements of materials, connections and sensors, and on (ii) calibration methodologies for ultra-precision displacement sensors using FPI, both approaches (i) and (ii) aiming for sub-nanometer accuracy. The concept (i) for dimensional stability measurements is a double-ended optical heterodyne interferometer [3]. A particular challenge in achieving picometer-level measurement uncertainty over longer periods of time (seconds to days) is the discrimination on intrinsic sample instability from other effects such as thermal expansion of both sample and interferometer bench. A dedicated balanced optical configuration is chosen in order to reduce the sensitivity of the instrument to such perturbations. Furthermore, for practical use in industrial applications, an intrinsic compensation of air refractive index variations is considered by means of a refractometer in a twin-interferometer configuration. For both concepts (i) and (ii) the targeted measurement accuracy requires validated alignment methodologies and measurement and correction of ambient conditions. Highest level accuracy is facilitated by the direct traceability to the VSL primary optical frequency standards.

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